

A Geodesic Climate Model With Quasi-Lagrangian Vertical Coordinates

We are developing a geodesic coupled ocean-atmosphere-land surface model designed for climate applications. The computational architecture of the model has been designed starting with a blank piece of paper, to allow maximally realistic coupled ocean-atmosphere-land surface simulations to be performed on emerging new computer architectures made accessible through the CCPP during the lifetime of the project. A key goal of the our project is to train young climate modeling researchers in all aspects of the climate modeling enterprise, including physical parameterizations, numerical methods, computational implementation, and scientific applications.

Our model makes efficient use of modern numerical algorithms and highly parallel computer architectures. Our project focuses on numerical methods and computational implementation; physical-parameterization research is included but not emphasized.

The atmosphere general circulation model (AGCM) is being developed through a collaborative effort involving Randall, Ringler, and Schubert of Colorado State University (CSU), Arakawa of the University of California at Los Angeles (UCLA), and Fulton of Clarkson University. The CSU AGCM split off from the UCLA AGCM in 1982, and has been undergoing extensive development since then. Meanwhile the UCLA AGCM, which traces its development back to the early 1960s, has also undergone extensive further development since 1982. The CSU and UCLA groups have maintained close communication and are pooling their efforts in the project, which makes use of numerical methods and physical parameterizations developed at both institutions.

The ocean general circulation model (OGCM) is based on POP, the Parallel Ocean Program developed at the Los Alamos National Laboratory (LANL). POP is a member of the Bryan-Cox family of ocean models and descends from the original 1969 formulation by Dr. Kirk Bryan of the Geophysical Fluid Dynamics Laboratory at Princeton University. Over the years, the formulation has been improved in many ways and kept up-to-date in terms of being optimized for the best available high-performance computers available at any given time. POP has been optimized both for massively parallel machines and clustered multi-processor nodes. POP provides an ideal framework within which to redesign the numerical hydrodynamics while retaining the important physics packages relevant to climate modeling as well as the parallel computing paradigm. A predecessor of POP, which had been modified by A. Semtner, Jr. (a Co-Investigator on this project) and R. Chervin so as to run efficiently with high spatial resolution on parallel vector computer architectures, formed the basis of a reorganized massively parallel POP developed by R. Smith and colleagues at LANL. The LANL team further modified the model to use a free surface, and introduced a “stretched” spherical coordinate system (see later discussion). Many other optimizations and physical parameterizations have since been incorporated. POP has been selected as the ocean model for the next version of the Community Climate System Model. POP provides an ideal framework within which to redesign the numerical hydrodynamics while

retaining the important model features relevant to climate modelling and high performance parallel computing.

In particular, POP was designed by LANL researchers for massively parallel computers, based on a version developed by A. Semtner, Jr. (a Co-Investigator on this project) and R. Chervin for parallel vector computers and used for high resolution simulations.

The land-surface model is SiB, the evolving “simple biosphere” model. Our project does not involve further development of SiB other than its implementation in the geodesic climate model. Development is ongoing, however, under other sponsorship. The land-surface model uses the same geodesic grid as the ocean model.

The atmosphere, ocean, and land-surface sub-models use geodesic discretizations of the sphere, based on the icosahedron. The ocean and land surface are discretized on a common geodesic “surface” grid (i.e., the same grid for both the ocean and the land surface), with higher resolution than the atmosphere. Sea ice is simulated on the ocean grid, with ice dynamics following the formulation developed at LANL by E. Hunke and colleagues. Coastlines will be specified on the high-resolution surface grid, so that a given atmosphere cell may be partly over ocean and partly over land. POP is now available with relatively general coordinates using map factors at each gridpoint. The ocean hydrodynamics can be reprogrammed following the example of the AGCM, and elliptic solvers are included as components of POP.

Within the framework of the geodesic grid discussed above, the atmosphere and ocean GCMs will use the “Z-grid” staggering of the variables in the horizontal, in which vorticity, divergence, and mass (temperature) are arranged on an un-staggered grid. This allows realistic simulation of geostrophic adjustment even when the grid size is larger than the radius of deformation, as can be the case particularly in ocean models.

Both the atmosphere and the ocean sub-models use highly conservative finite-volume discretization methods based on the ideas of A. Arakawa and colleagues.

Both the atmosphere and the ocean sub-models use quasi-Lagrangian vertical coordinates developed by our team members at UCLA and by R. Bleck of LANL, in order to minimize the effects of the truncation errors associated with vertical advection. J. Baumgardner of LANL is taking the lead on implementing a quasi-Lagrangian coordinate in our geodesic version of POP.

The AGCM uses an innovative multi-layer embedded planetary boundary layer, developed by our team members from UCLA.

Both the atmosphere and the ocean sub-models use numerical methods that permit large time steps by eliminating the computational instability that would otherwise be associated with rapidly propagating external gravity waves.

The coupled model is designed for efficient parallel execution on many processors; in particular, it includes a parallel or “distributed” flux-coupler that takes advantage of the planned

conformity between the geodesic grids used to represent the atmosphere and the ocean and land surface.

The coupled model can run with a variety of horizontal and vertical resolutions for the ocean and atmosphere, but at present our “target” resolution for the atmosphere will use 120-km geodesic cells, with 64 layers extending through the stratosphere, while our target resolution for the ocean is 30-km geodesic cells, with 50 layers. These target resolutions can and will be adjusted as the computing resources available to us evolve over the lifetime of the CA.

In summary, an architecturally unified modeling framework based on geodesic grids and quasi-Lagrangian vertical coordinates will allow for the creation of a comprehensive, conservative, accurate, portable, and highly scalable coupled climate model. We believe that this approach is the future of climate modeling.